

Excited structure with a very extended shape in ^{108}Cd

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High-spin states in ^{108}Cd were populated in the reaction $^{64}\text{Ni}(^{48}\text{Ca},4n)$ at a beam energy of 207 MeV. Gamma-ray spectroscopy was performed with the Gammasphere spectrometer. A new excited band was found. The quadrupole moment measured using the method of residual fractional Doppler shifts has a value of $Q_0 = 8.5 e b$, which corresponds to an axis ratio of $c/a = 1.72$.

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Recent cranked Strutinsky calculations by Chasman [1] predict many very extended shape minima at high angular momenta in the mass $A \approx 100$ region. These calculations used a four-dimensional shape parametrization taking into account quadrupole, octupole, and hexadecapole deformations and a necking degree of freedom. The calculated minima become yrast only at very high angular momenta, close to the expected fission limit, and, consequently, the barrier to fission is often very small, making experimental observation difficult. Another experimental restriction is that many of the nuclides showing pronounced minima cannot be reached in a heavy-ion-induced fusion reaction with stable beams and targets.

From both the theoretical predictions and the experimental possibilities, ^{108}Cd is a promising candidate for investigating very high deformation. In the calculations, a pronounced minimum at a deformation corresponding to an axis ratio of $c/a = 2.3$ results from shell corrections for both protons and neutrons. This deformation is significantly larger than those observed for superdeformed bands in various mass regions. This structure is calculated to become yrast at $I \approx 60\hbar$, and at this angular momentum the height of the fission barrier was 9.1 MeV, implying that any structures populated are likely to survive against fission.

Other cranked Strutinsky calculations by Werner and Dudek [2] predict a stable secondary minimum at a large deformation of $\beta_2 \approx 0.7$, which develops at a similar angular momentum of $\sim 60\hbar$. This deformation corresponds to an axis ratio of $c/a \approx 1.9$.

An experiment to search for such structures in ^{108}Cd was performed at the ATLAS accelerator facility at Argonne National Laboratory. High-spin states in ^{108}Cd were populated in the reaction $^{64}\text{Ni}(^{48}\text{Ca},4n)$ at a beam energy of 207 MeV. Gamma rays were detected with the Gammasphere spectrometer [3] which consisted of 101 Compton-suppressed germanium detectors at the time of the experiment. The tar-

get comprised a stack of two ^{64}Ni foils with a thickness of $500 \mu\text{g}/\text{cm}^2$ each. Events were written to tape when at least six germanium detectors gave coincident signals after Compton suppression and a total of 1.3×10^9 events were recorded on magnetic tape.

In the off-line analysis the data were stored on disk in an indexed, energy-ordered database with the program BLUE [4]. The BLUE database and the accompanying “query” routines provide the capability to create spectra under various gating conditions in multiple dimensions on an interactive or near-interactive time scale. For this analysis the database contained the γ -ray energies, the angles of the detectors in which the γ ray was detected, and the fold of the event. In addition, an E_γ - E_γ - E_γ cube was sorted in order to search for band structures.

An earlier publication reported the observation of a band in ^{108}Cd which is associated with a very extended shape [5]. The lower limit of the axis ratio for this band was found to be $c/a > 1.8$, which placed it among the most deformed structures ever observed in nuclei, and an even larger deformation as predicted by Chasman could not be ruled out.

In this paper, we report the observation of an excited band, with properties similar to those of the previously reported structure. A spectrum of this new band, band 2, is shown in Fig. 1. The new band could only be firmly identified and assigned to ^{108}Cd when the γ -ray multiplicity K of the event was used to select those events populated at the highest angular momenta. In Gammasphere, K is defined as the number of modules that detected a γ ray, where a module is a HPGe detector and its surrounding BGO suppression shield. Since the BGO suppressors were shielded from direct radiation from the target, the number of modules that register a signal provided only a crude measure of the γ -ray multiplicity in the reaction. Nevertheless, this method proved effective in selecting high-spin events and in reducing the low-spin background, so that the overall quality of the spectrum was significantly improved. The spectrum shown in Fig. 1 is double gated on the in-band transitions, where each event was analyzed in its native fold using the BLUE software. Only events with fold $K \geq 22$ were used to generate the spectrum.

About 15% of the fusion evaporation cross section leads to ^{108}Cd . The intensity of band 2 is about 0.6% of this reac-

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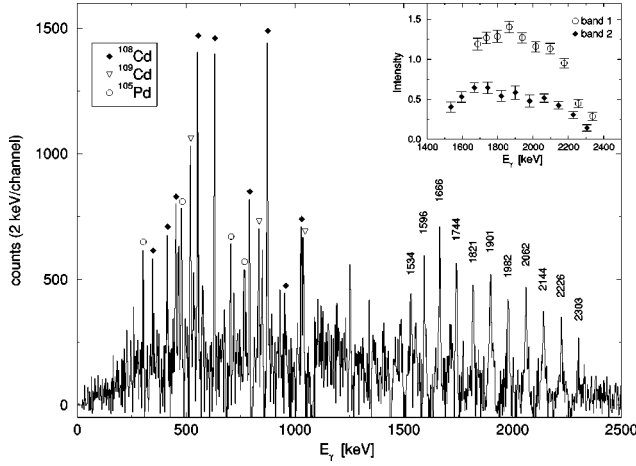


FIG. 1. Sum of all combinations of double gates on in-band transitions. Only events corresponding to a fold $K \geq 22$ were used.

tion channel, compared to 1.4% for band 1. The intensity patterns of both bands are shown in the inset of Fig. 1.

The assignment of band 2 to ^{108}Cd is based on γ -ray coincidence relationships. The strongest lines seen in coincidence with band 2 belong to the known γ rays of ^{108}Cd [6]. This is also true when looking at individual combinations of gates on in-band transitions, except for gate combinations which include the 1596 and 2144 keV transitions which have similar energies as transitions in a strongly populated normal deformed band in ^{105}Pd [7]. Although gates on these transitions are responsible for contamination of the spectrum with ^{105}Pd lines at low energy, they improve the overall quality of the summed spectrum for band 2 and were therefore used for the spectrum in Fig. 1. The presence of lines belonging to ^{109}Cd at low energies is due to background from the quasi-continuum part of the spectrum, which happens to be in the same energy region as the band. The γ -ray multiplicity for the $3n$ channel leading to ^{109}Cd is on average higher than that for the $4n$ channel, resulting in a different shape of the “E2 bump.” This makes background subtraction difficult when gating over the whole energy range of the band with changing contributions of the quasicontinuous γ rays from the different reaction channels.

A comparison of the dynamic moment of inertia $J^{(2)}$ is shown in Fig. 2. Both bands show a very similar behavior with a constant $J^{(2)}$ of the same magnitude at high frequencies and a sharp increase of $J^{(2)}$ at low frequencies, which likely indicates a change in the nucleon configuration. In the intermediate-frequency range the transition energies of one band lie in between those of the other band. However, at the highest frequencies the energies deviate from the midpoint by several keV. Therefore it seems unlikely that bands 1 and 2 are signature partner bands. For comparison Fig. 2 shows also the calculated moments of inertia for a rigid rotor of prolate axial symmetric shape as dashed lines for axis ratios of 3:2, 2:1, and 3:1, respectively.

From the similarity of the dynamic moments of inertia one can conclude that both bands lie in the same spin region. Since neither of the bands could be linked to lower-lying states, the exact spins remain unknown. Because of the sharp

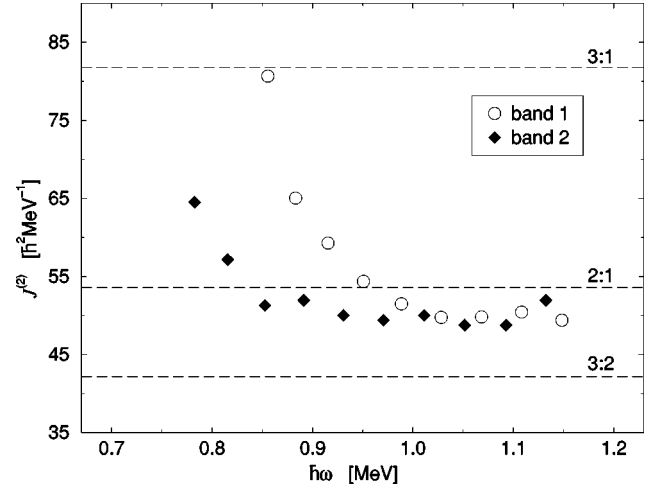


FIG. 2. Comparison of the dynamic moment of inertia as a function of rotational frequency for bands 1 and 2 in ^{108}Cd . The dashed lines show calculated moments of inertia for a prolate rigid rotor for various axis ratios.

increase in the dynamic moment of inertia, it is difficult to obtain an estimation of the spins from a parametrization of $J^{(2)}$ in powers of the rotational frequency ω . The best estimation one can get for the spins is to assume that the kinematic moment of inertia $J^{(1)}$ and the dynamic moment of inertia $J^{(2)}$ are equal at the highest angular momentum, where $J^{(2)}$ is flat, although there is no *a priori* reason to assume that the nucleus behaves like a rigid rotor. Under these assumptions one can estimate that band 1 lies in the spin range between $40\hbar$ and $60\hbar$ and band 2, which is observed to lower frequencies, continues slightly lower in spin. For both bands the highest angular momentum state corresponding to known transitions in ^{108}Cd and observed in coincidence with the band is a 16^+ state, leaving a large number of transitions in the decay of the bands unobserved. Some lines seen in coincidence with band 2 could not be identified and might be involved in the highly fragmented decay of the band.

The in-band transitions are extremely fast and the states decay while the recoiling nucleus traverses the thin target. Residual Doppler shifts [8] of the eight strongest in-band transitions were measured and the corresponding average recoil velocity for each of the transitions was determined. The fractional Doppler shifts $F(\tau) = \beta/\beta_0$, with β_0 being the average initial recoil velocity, are plotted in the right panel of Fig. 3. The left panel shows the fractional Doppler shifts for band 1 taken from Ref. [5] for comparison. Since the intensity of band 2 is significantly weaker than the intensity of band 1, the uncertainties for band 2 are larger. The uncertainty in the determination of the initial recoil velocity, due to uncertainties in the target thickness and in the beam energy, is represented by the dotted lines in Fig. 3.

Calculated $F(\tau)$ curves are shown for $Q_0 = 7, 9$, and $14 e b$ for both bands. The stopping powers of Ziegler *et al.* [9] were used for these calculations. The intensities of the side-feeding transitions were fitted to the data, and it was assumed that they have the same quadrupole moment as the in-band transitions. To check the consistency of the method,

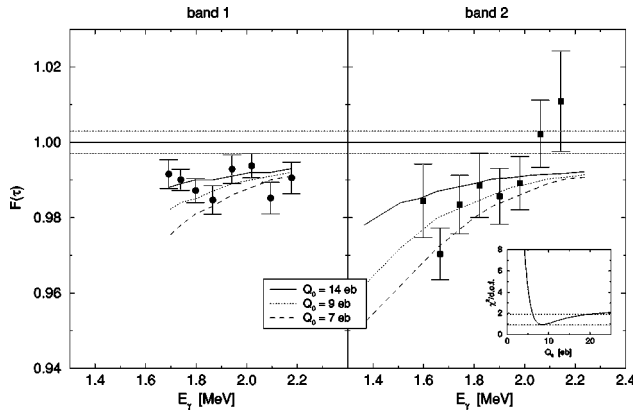


FIG. 3. Comparison of the experimentally deduced $F(\tau)$ values for the two bands in ^{108}Cd . Data for band 1 (left panel) are taken from Ref. [5]. Calculated $F(\tau)$ values are shown for $Q_0 = 7, 9$, and 14 e b, respectively, for both cases. The uncertainty of the initial recoil velocity is represented by the dotted lines. The inset shows a χ^2 fit of the calculated $F(\tau)$ curves to the data for band 2.

an $F(\tau)$ curve was calculated for a normal deformed band in ^{104}Pd [7], using the quadrupole moment from an independent measurement, and compared to the values obtained in this experiment with very good agreement [5]. The large errors of the $F(\tau)$ values for band 2 do not allow an accurate measure of the quadrupole moment. A χ^2 fit to the data of band 2 is shown in the inset of Fig. 3. One finds a minimum at $Q_0 = 8.5$ e b, which corresponds to an axis ratio of $c/a = 1.72$. The χ^2 rises steeply for lower quadrupole moments and the lower limit compatible with a 1σ error is $Q_0 = 6.2$ e b. This lower limit corresponds to an axis ratio of $c/a > 1.52$. The minimum is very shallow for high quadrupole moments, so that no reasonable upper limit can be given.

As a result of the higher intensity, the $F(\tau)$ values for band 1 [5] are more accurate. However, only a lower limit of

$Q_0 > 9.5$ e b could be given for the quadrupole moment of band 1. That corresponds to an axis ratio of $c/a > 1.8$ and to one of the most deformed structures ever observed in nuclei. Although the analysis for band 2 yielded a slightly lower value for the quadrupole moment, it is reasonable to believe that the deformation for band 2 is comparable to the one for band 1.

Although the accuracy of the lifetime measurements is not high enough to clearly associate the observed bands with the minimum at extreme deformation predicted by Chasman [1], such a high deformation cannot be ruled out on the basis of the data. The discussion of the configurations of these bands remains speculative. The involvement of the neutron $i_{13/2}$ intruder orbital, which is important for the stabilization of the second minimum in the $A \approx 130$ superdeformation (with an axis ratio of $\approx 3:2$) seems likely. This case represents an important test of nuclear structure theory and may provide more insight into which essential ingredients are needed for reliable models of nuclei at such extreme deformations.

In summary, an excited band based on a very extended shape has been found in ^{108}Cd with properties very similar to those of the first band observed in this nucleus. Lifetime measurements using the residual fractional Doppler-shift method suggest a very large deformation. A better understanding of these extremely deformed structures may point the way to the long-predicted phenomenon of hyperdeformed nuclei.

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